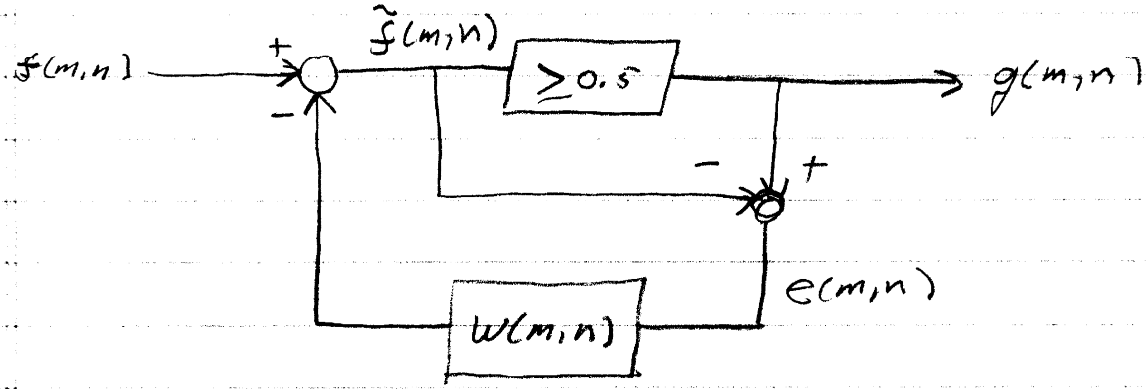
Error Diffusion

Lecture 27

◦ Objective: Use values of local pixels and image to improve halftone quality.



$$\tilde{f}(m,n) = f(m,n) - W(m,n) * e(m,n)$$

$$g(m,n) = Q(\tilde{f}(m,n)) = \tilde{f}(m,n) \geq 0.5$$

$$e(m,n) = g(m,n) - \tilde{f}(m,n)$$

$W(m,n)$ is <u>strictly</u> causal

- Two ways to think about error diffusion

1) Add up previous errors

$$\tilde{f}(m,n) = f(m,n) - \sum_{k}\sum_{l} w(k,l)\, e(m-k, n-l)$$

$$e(m,n) = g(m,n) - \tilde{f}(m,n)$$

$w(1,1)$	$w(1,0)$	$w(1,-1)$
$w(0,1)$	X	

- useful for analysis
- simple filtering

2) "Diffuse" errors forward

$$\tilde{f}(m,n) \leftarrow \tilde{f}(n+k, n+l) - w(k,l)\, e(m,n)$$

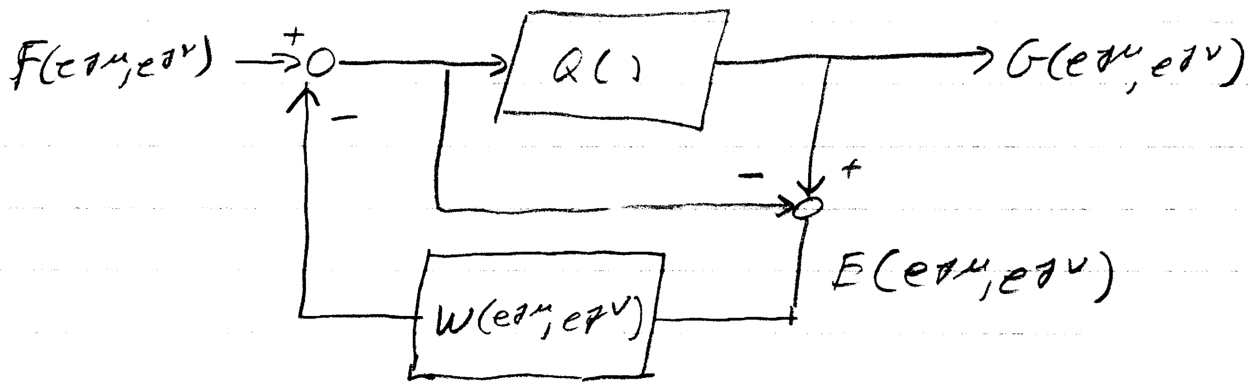
$$e(m,n) = g(m,n) - \tilde{f}(m,n)$$

	X	$w(0,1)$
$w(1,-1)$	$w(1,0)$	$w(1,1)$

- More intuitive
- Sooner or later signal gets quantized

More analysis

Lecture 28

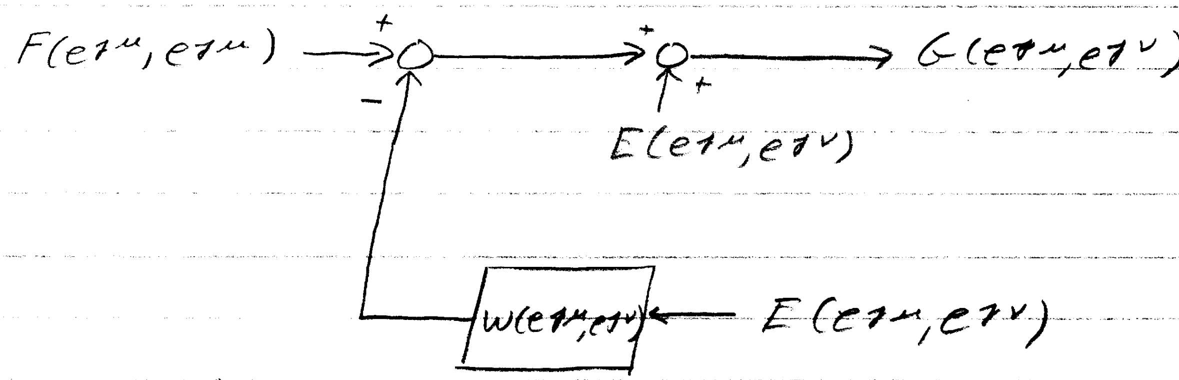


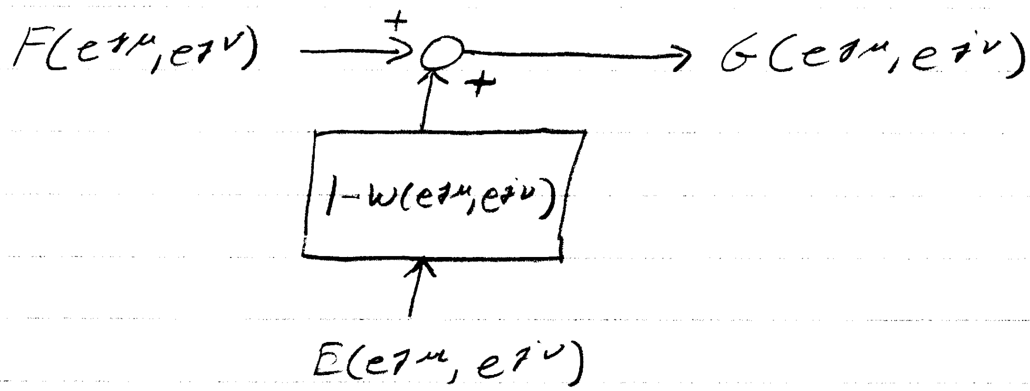
- Assume that $e(m,n)$ are i.i.d uniformly distributed on $[0.5, 0.5]$ =

$$\Rightarrow \quad E[e(m,n)] = 0$$

$$E[e(m,n)\, e(m+k, n+l)] = \frac{\delta(k,l)}{12}$$

$$\Rightarrow \quad S_e(e^{j\mu}, e^{j\mu}) = \frac{1}{12} \Leftarrow \text{white noise}$$





$$G(e^{j\mu},e^{j\nu}) - F(e^{j\mu},e^{j\nu}) = \text{display error}$$

$$= \underbrace{\left(1 - W(e^{j\mu},e^{j\nu})\right)}_{\text{spectral shaping filter}} E(e^{j\mu},e^{j\nu})$$

Comments

1) $1-W(e^{j\mu},e^{j\nu})$ should be high pass
2) $1-W(e^{j0},e^{j0}) = 0 \Rightarrow \sum_k \sum_l w(k,l) = 1$
3) i.i.d. assumption is poor, but if $\sum_k \sum_l w(k,l) = 1 \Rightarrow G(e^{j0},e^{j0}) = 0$

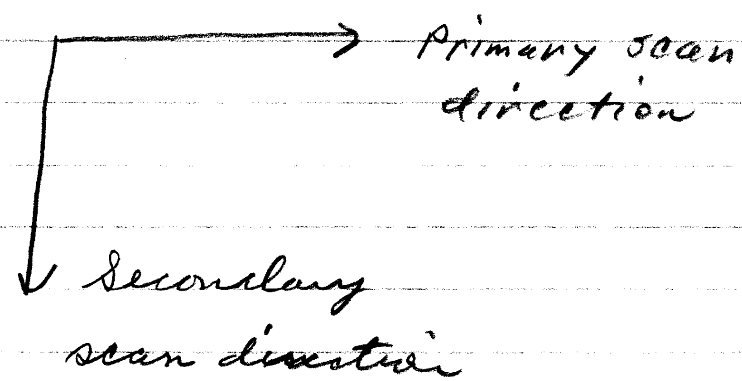
Typical filters for error diffusion

Floyd Steinberg

		7/16
3/16	5/16	1/16

Jarvis, Judice and Ninke

			7/48	5/48
3/48	5/48	7/48	5/48	3/48
1/48	3/48	5/48	3/48	1/48



Better model for $E(e^{j\mu}, e^{j\nu})$

- Quantizer error spectrum is correlated with image
- For a particular filter, this correlation may be measured.

New model

$$e(m,n) = c\,f(m,n) + r(m,n)$$

$\uparrow$ i.i.d

$c \leftarrow$ correlation with $f(m,n)$

Floyd + Steinberg $c \cong 0.55$
Jarvis, Judice + Ninke $c \cong 0.80$
(Binary quantization)